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(54) Abstract Title
Manufacture of a rigid contact lens with a smooth, aspherical back surface

(57)   A process for the manufacture of a rigid contact lens 2 with a smooth, aspherical back surface 3 of a defined geometry comprises selecting an analogous lens which has the desired optical and dynamic properties, and which has a back surface of generally spherical geometry. This back surface comprises a co-axial multicurve, defining, for example, a central zone and peripheral zones, and having a discontinuity at each point where the radii of adjacent component curves of the multicurve intersect. The back of this analogous lens is mathematically analysed and the results are used to construct a formula which defines the geometry of the desired smooth aspherically curved surface. The formula is used to generate data to control the action of a shaping device which forms the smooth aspherically curved back surface of the lens according to the defined geometry. Also disclosed is a rigid contact lens with a smooth aspherical back surface, but which has a central optic zone with a spherically curved back surface.
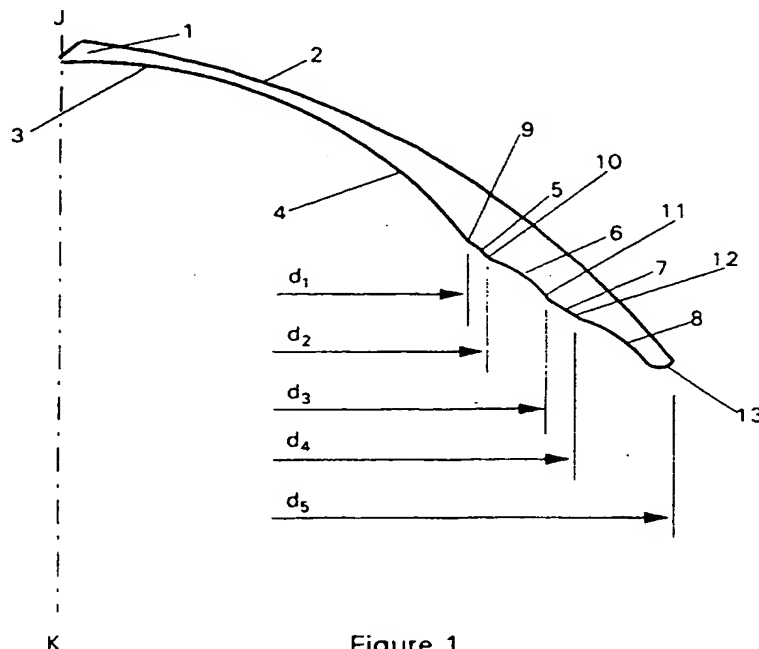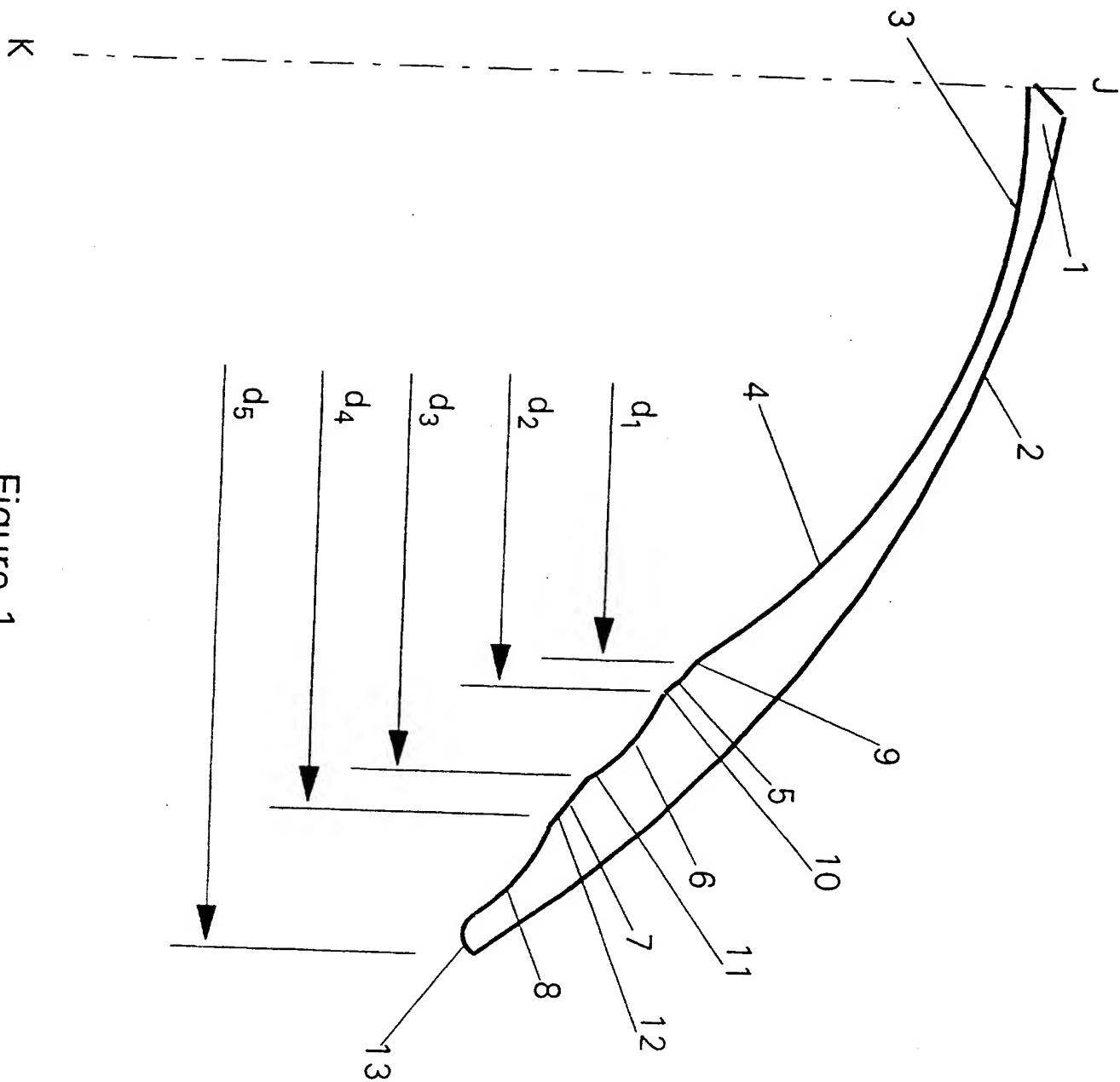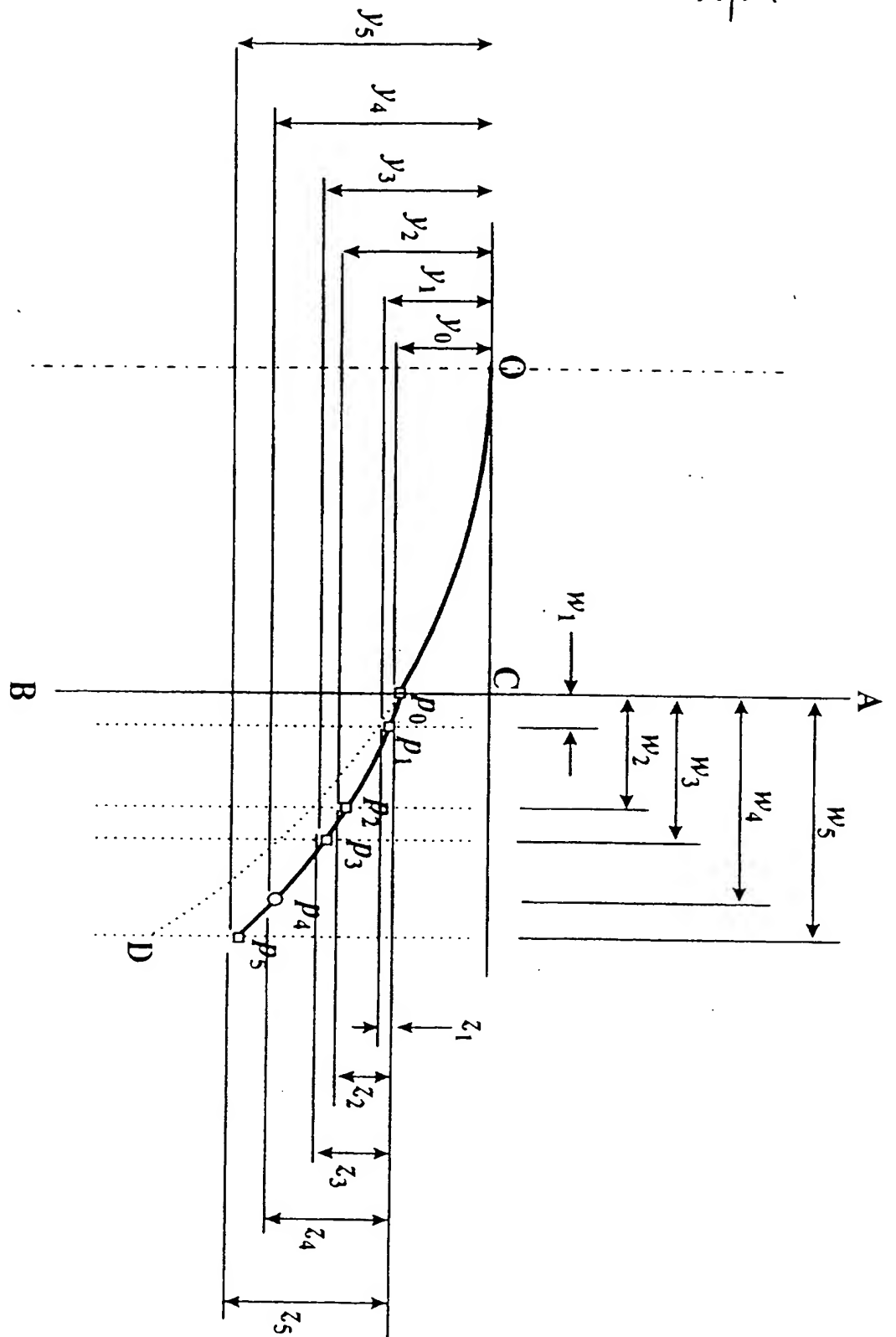
Figure 1

GB 2 327 283 A

Figure 1

Figure 2

MANUFACTURE OF CONTACT LENSES

This invention relates to a process for the manufacture of a rigid contact lens having a smooth, aspherically curved back surface of defined geometry, a process for shaping the back surface of a rigid contact lens to produce a smooth, aspherically curved surface of defined geometry and a rigid contact lens produced by such processes.

The surface of a contact lens which sits on the eye when the lens is worn is known as the back surface and all rigid lens design classification is based on the arrangement of the back surface parameters. Thus, lenses which have back surfaces derived from spheres are broadly referred to as "spherical" and lenses which include non-spherical zones are broadly described as "aspheric".

The back surface of a contact lens can be divided into two distinct zones. The first zone, which is centrally located, is referred to as the back central optic zone and it is through this zone that the lens-wearer sees. The second zone surrounds the back central optic zone and determines the lens-cornea relationship, that is, how the lens sits on the eye and how it behaves dynamically. This zone is referred to as the peripheral zone and the associated radius and diameter are known as the peripheral zone radius and peripheral zone diameter. Often, a lens will have more than one contiguous peripheral zone, each peripheral zone having its own associated peripheral zone radius and peripheral zone diameter. In such circumstances, the various peripheral zones of spherical lenses can be arranged co-axially.

The design-related competitiveness between different rigid lens products is critically related to the arrangement of the peripheral zone or zones. There are therefore many design concepts and several variations on each of the principal categories of lens.

One such product is produced by Madden & Layman Ltd. of St. Leonards-on-Sea, Sussex, England and is sold under the trade name "Maxim". This product is based on a traditional spherical rigid lens design which is described as a co-axial multicurve and, in this particular case, the design is based on a 3-curve co-axial multicurve. Thus, this lens is based on a design which comprises a back central optic zone and two peripheral zones.

A feature of this product is that the values of the peripheral radii and diameters are such that the stand-off at the edge of the lens, when placed on an average human cornea, is a constant value throughout the range. Similarly, the clearance between the apex of the back surface of the lens and the apex of the cornea in a typical case is also an approximately constant value.

When this type of lens was first produced, the central optic zone was cut with a lathe and the peripheral zones were generated by a grinding process using diamond coated tools. Later, as the lathing process evolved and automation was gradually introduced, the accuracy and reproducibility of lathing improved to the extent where the peripheral curves could also be cut by lathe as part of the process of producing the back surface.

By the end of the 1980s, spherical lathing technology had improved to a level where the complete back surface could be cut with credible reproducibility. The process involved setting the lathe for successive radii in turn and then repositioning the workpiece to cut each radius. However, this required that the workpiece be positioned with very high accuracy, typically within 5 microns of the target position.

Following lathing, the complete back surface was polished to give a high quality optical finish and this polishing process had the effect of blending together adjacent peripheral radii. The process of polishing and

blending, which is still a manual process, therefore had a critical influence on how the lens sat on the eye and the comfort characteristics of the lens.

As the development of automatic lathes has continued, lathes have become available within the last 5 years or so which can accurately move the position of the cutting tool while a cut is being taken. These lathes are generally described as having "aspheric capability" as they are not limited to spherical shapes, as previous lathes have been, but can cut almost any geometry which can be described mathematically and have that description translated into a set of instructions which is capable of being interpreted by the lathe control system.

Such aspheric capability lathes have now been used for several years to generate the "Maxim" lens described above. Moreover, the accuracy and reproducibility of these lathes is such that it has become possible to cut two intermediate "blend radii" at the point where the curves of the central optic zone and the adjacent first peripheral zone intersect and the point where the curves of the two peripheral zones intersect thereby generating a back surface which effectively has four peripheral zones. The additional intermediate blend radii have values which are approximately mid-way between adjacent radii of the basic 3-curve lens and are designed to act as a blend between adjacent radii. In addition, the use of such aspheric capability lathes has allowed some rounding of the edge of the lens to be incorporated into the design by cutting a so-called "edge radius".

The introduction of these intermediate blend radii had the effect of reducing the work required by the polishing process to produce a well-blended surface and thus resulted in a more reproducible lens. A similar benefit also resulted from the use of the aspheric capability lathe to cut a rounded edge profile. However, the back surface of the lens following lathing still contains four discontinuities at the points where the

radii of adjacent zones intersect, namely, where the
radii of the central optic zone and innermost
intermediate blend zone, the innermost intermediate blend
zone and innermost peripheral zone, the innermost
peripheral zone and outermost intermediate blend zone and
the outermost intermediate blend zone and outermost
peripheral zone respectively intersect. Thus, although
reduced from previous levels, an extensive polishing
process is still essential to produce a lens having a
well-blended surface which can be comfortably worn by the
lens-wearer and will have the desired optical and dynamic
characteristics.

The production of other lens designs based on
spherical geometry has undergone a similar evolution over
the years with the advent of improved lathe technology.
However, since all such lens designs must contain at
least one peripheral zone of different radius to the back
central optic zone in order for the back surface of the
lens to fit the eye, the back surface of all such lenses
after lathing will contain at least one discontinuity
which must be blended by manual polishing as described
above.

It is therefore apparent that there is a need for a
process which allows the formation of a lens which has a
back surface which is shaped to change smoothly and
continuously rather than in discreet steps thereby
obviating the production of discontinuities in the
surface and the consequent need for an extensive
polishing and blending process but which still has the
desired optical and dynamic characteristics.

According to the invention there is therefore
provided a process for the manufacture of a rigid contact
lens having a smooth, aspherically curved back surface of
defined geometry which comprises selecting an analogous
lens which has the desired optical and dynamic properties
and a back surface of generally spherical geometry
comprising a co-axial multicurve having a discontinuity

at each point where the radii of adjacent component curves of the multicurve intersect, subjecting the back surface of the analogous lens to mathematical analysis, using the results of the analysis to construct a mathematical formula which defines the geometry of the desired aspherically curved surface and using the mathematical formula to generate data to control the action of a shaping device which forms the aspherically curved back surface of the lens according to the defined geometry.

According to a second aspect of the invention there is provided a process for shaping the back surface of a rigid contact lens to produce a smooth, aspherically curved surface of defined geometry which comprises selecting an analogous lens which has the desired optical and dynamic properties and a back surface of generally spherical geometry comprising a co-axial multicurve having a discontinuity at each point where the radii of adjacent component curves of the multicurve intersect, subjecting the back surface of the analogous lens to mathematical analysis, using the results of the analysis to construct a mathematical formula which defines the geometry of the desired aspherically curved surface and using the mathematical formula to generate data to control the action of a shaping device which forms the aspherically curved back surface of the lens according to the defined geometry.

Preferably, the back surface is rotationally symmetrical.

In a preferred form of the process, the mathematical analysis involves measuring selected parameters of the analogous lens and it is particularly preferred that the selected parameters are the radii and diameters of the component curves of the co-axial multicurve back surface. In some cases, it may be advantageous to select at least one additional point on at least one of the component curves and to measure the selected parameters for each

additional point.

Preferably, the values of the selected parameters are subjected to a mathematical process which results in a mathematical formula which is preferably in the form of a derived polynomial which describes a geometric shape which matches exactly the central optic zone of the analogous lens and replaces the discreet peripheral zone or zones of the analogous lens by a single smooth and continuous peripheral zone. Thus, the mathematical formula is preferably constructed so that its resulting surface of revolution is mathematically smooth and continuous at each point which corresponds to a discontinuity in the back surface of the analogous lens. In this context, the expression "mathematically smooth and continuous" means that the surfaces of adjacent component curves have a common tangent at their point of intersection.

It is also preferred that the order of the derived polynomial is determined by the number of discontinuities in the co-axial multicurve analogous lens or, if at least one additional point has been selected, by the number of discontinuities and additional points.

It is particularly preferred that the analogous lens is a 5-curve multicurve lens, especially of the type described above in relation to the "Maxim" product. In such cases, it is preferred that an additional point on the 5-curve multicurve back surface is selected and, preferably, this additional point should be located within the curve of the outermost peripheral zone to compensate for the width of this zone. Consequently, the mathematical formula constructed for such a 5-curve multicurve lens including an additional point will preferably be a derived polynomial of order 6.

Preferably, the data generated from the mathematical formula comprises a set of instructions capable of being interpreted by a control system of the shaping device. The shaping device is preferably a cutting tool,

especially a diamond cutting tool, and it is particularly preferred that the shaping device is a computer numerically controlled lathe. Suitable lathes of this type are produced by City Crown Limited of 14 Kempson Close, Aylesbury, Buckinghamshire HP19 3UQ.

To complete the manufacture of a rigid contact lens, the front surface can be prepared by any standard technique according to the optical prescription of the lens wearer.

The invention also embraces a rigid contact lens having a smooth, aspherically curved back surface produced by a process as defined above.

In addition to the advantages in the production of such lenses referred to above, such as increased reproducibility and facilitation of the polishing process, it has been found that such lenses have additional desirable performance characteristics when compared to a conventional co-axial multicurve lens. For instance, the fact that the transition between the back central optic zone and the first peripheral zone is mathematically smooth and continuous is thought to improve the dynamic characteristics of the lens on the eye. Also, the combination of a spherical central optic zone, which is generally agreed to provide better quality optical performance, with an aspheric periphery, which is thought to improve comfort, adaptation and general wearing characteristics, optimises the overall performance of such a lens. Moreover, since the back surface of such a lens is modelled on the geometry of an existing co-axial multicurve lens, current wearers of such existing lenses should be able to convert to wearing a lens according to the invention with none of the discomfort which is normally associated with a change of lens shape.

It is also envisaged that a rigid contact lens having a smooth, aspherically curved back surface of the type produced by the process of the invention and thus

exhibiting similar enhanced performance characteristics could be manufactured by an alternative process such as moulding.

According to a further aspect of the invention there is therefore provided a rigid contact lens having a smooth aspherically curved back surface comprising a central optic zone having a spherically curved back surface and a plurality of peripheral zones in which the radii of adjacent zones have a common tangent.

Preferably, the rigid contact lens comprises a central optic zone and four peripheral zones.

A specific embodiment of the invention will now be described more fully with reference to the accompanying drawings in which:-

Figure 1 is a schematic representation of part of a rigid contact lens having a 5-curve co-axial multicurve back surface; and

Figure 2 is a schematic representation of the back surface of the part-lens of Figure 1.

Figure 1 shows part of an analogous rigid contact lens 1 having a front surface 2 and a back surface 3. The central axis of lens 1 is denoted by broken line J-K. The back surface 3 is a 5-curve co-axial multicurve comprising central optic zone 4 and peripheral zones 5, 6, 7, 8. Peripheral zones 5 and 7 may also be referred to as intermediate blend zones. The radii of central optic zone 4 and peripheral zones 5, 6, 7 and 8 are denoted r_1, r_2, r_3, r_4 and r_5 respectively and the diameters are denoted d_1, d_2, d_3, d_4 and d_5 respectively. Discontinuities 9, 10, 11, 12 arise at each point where the radii r_1, r_2, r_3, r_4, r_5 of adjacent component curves intersect. Lens 1 also has a rounded edge profile 13.

The mathematical analysis of the back surface 3 of lens 1, and the construction of a derived polynomial to define the geometry of the desired back surface in the lens produced according to the process of the invention may be carried out as follows with reference to Figure 2.

Polynomial curve fitting is a widely used technique for function approximation in which a polynomial is used to fit a set of data points by the technique of minimizing an error function such as the root-mean-square.

Consider the Mth-order polynomial given by

$$p(x) = c_o + c_1 x + ... + c_M x^M = \sum_{j=0}^{M} c_j x^j \quad ..... \quad (1)$$

This can be regarded as a non-linear mapping which takes x as input and produces p as output. The precise form of the function $p(x)$ is determined by the values of the parameters $c_0, ..., c_j$.

In order to find a polynomial which will best fit the function under consideration, it is necessary to decide on the order of the polynomial, M, and the parameters c_j. It is important to choose a value of M which best suits the requirements of the particular physical situation. If too few terms are included, the polynomial may not provide a good approximation and equally if too many terms are included the approximation may also be incorrect. The inclusion of too many terms is referred to as over-fitting.

If a matrix A has the following format:

$$A = \begin{matrix} 1 & a_1 & a_1^2 & ... & a_1^{n-1} \\ 1 & a_2 & a_2^2 & ... & a_2^{n-1} \\ ... & ... & ... & ... & ... \\ 1 & a_n & a_n^2 & ... & a_n^{n-1} \end{matrix} \quad .... \quad (2)$$

it can be shown that the determinant of this matrix is:

$$det(A) = (a_2 - a_1)(a_3 - a_1)(a_3 - a_2)(a_4 - a_1)(a_4 - a_2)(a_4 - a_3)$$
$$... (a_n - a_{n-1}) \quad .... \quad (3)$$

This form of determinant is often called *Vandermonde's determinant*.

A typical set of values for the 5-curve co-axial multicurve lens shown in Figure 1 is shown in Table 1 below:-

	r	d
1	7.80	7.70
2	8.05	7.90
3	8.30	8.50
4	9.38	8.70
5	10.45	9.30

The centres of the overlapping spheres defined by the five pairings (r_i, d_i) all lie along the lens axis J-K. The generating curve defined by these basic lens dimensions can be visualised as in Figures 1 and 2. The central radius, r_1, forms the central optic zone 4 and the surrounding radii $r_2, ..., r_5$ define the peripheral zones 5,6,7,8.

The design objective is to develop a polynomial based on the specific values for lens 1 that will:
   a) exactly replicate the current design across the central optic zone 4; and
   b) closely approximate the current lens across the peripheral zones 5,6,7,8.

The strategy is to find a polynomial that will pass through the points where the arcs of the defining circles intersect, while embodying the curve fitting characteristics given above.

In a preliminary study devised to decide on an appropriate order for the polynomial, it was established that, due to the width of the outermost peripheral zone 8, an extra point should

be inserted in this zone. This is shown as point p_4 in
Figure 2. With this point in place, the two outermost
peripheral zones defined by points p_3, p_4 and p_5 would have the
same radius value, r_5.

In order to set up a scheme of calculation it is necessary
to define certain parameters of the lens geometry. Some of
these are shown in Figure 2.

The points where the original five curves of lens 1
intersect successively are denoted by p_0, p_1, p_2, p_3 and p_5. The
additional point is denoted by p_4. Other parameters of the
geometry are developed as follows.

To establish the polynomial that will fit the lens curve,
a mapping is set up from w_i to z_i.

$$z = p(w) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (4)$$

where w_i are the distances (bandwidths) from points p_i to the
line AB; w could be considered as a 'bandwidth function' as
follows:

$$w = f(x) = x - OC \quad \dots\dots\dots\dots\dots\dots \quad (5)$$

where x is the distance from the lens axis.

The dimensions denoted by z_i correspond to purposeful,
specified values of axial lift, measured parallel to the lens
axis from the corresponding point p_i. In Figure 2, z_1 denotes the
vertical distance from point p_1 to the arc defined by extending
the back optic zone radius, r_1.

Equation 4 can therefore be written as a polynomial in the
following format of order 6 and will define a curve that passes
through the 6 points p_0, ..., p_5.

$$z = c_0 + c_1 w + c_2 w^2 + c_3 w^3 + c_4 w^4 + c_5 w^5 + c_6 w^6 \quad (6)$$

This equation can be simplified further. At the point p_0, $w_0 = 0$ and $z_0 = 0$, so $c_0 = 0$. It is also evident that $c_1 = 0$. With these changes, equation 6 becomes:

$$z = c_1 w^2 + c_2 w^3 + c_3 w^4 + c_4 w^5 + c_5 w^6 \quad \ldots \ldots \quad (7)$$

with the coefficients re-ordered for ease of manipulation.

It is obvious from Figure 2 that the values of w_i can be obtained as follows:

$$w_1 = (d_2 - d_1)/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$w_2 = (d_3 - d_1)/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

$$w_3 = (d_3 - d_1)/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

$$w_4 = (d_4 - d_1)/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

$$w_5 = (d_5 - d_1)/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

In order to calculate z_i, it is necessary to calculate the vertical distances from points p_i to the x-axis, which are denoted as y_i in Figure 2. From Figure 2, it can be seen that the distances y_i are related to the sagittal heights of overlapping spheres. The values of y_i can be calculated from the following equations, derived from the geometry of the position as shown in Figure 2.

$$y_0 = r_1 - \sqrt{r_1^2 - (d_1/2)^2} \quad \ldots\ldots\ldots\ldots\ldots \quad (13)$$

$$y_1 = y_0 - \sqrt{r_2^2 - (d_1/2)^2} - \sqrt{r_2^2 - (d_2/2)^2} \quad (14)$$

$$y_2 = y_1 - \sqrt{r_3^2 - (d_2/2)^2} - \sqrt{r_3^2 - (d_3/2)^2} \quad (15)$$

$$y_3 = y_2 - \sqrt{r_4^2 - (d_3/2)^2} - \sqrt{r_4^2 - (d_4/2)^2} \quad (16)$$

$$y_4 = y_3 - \sqrt{r_5^2 - (d_4/2)^2} - \sqrt{r_5^2 - (d_5/2)^2} \quad (17)$$

$$y_5 = y_4 - \sqrt{r_6^2 - (d_5/2)^2} - \sqrt{r_6^2 - (d_6/2)^2} \quad (18)$$

The set of values y_i is the set of values of the sagittal height of the lens at the corresponding diameter d_i.

At each point p_i, the value of axial lift z_i may be calculated by subtracting the corresponding y_i value from the sagittal height of the back optic zone radius, r_1, and the corresponding diameter d_i. This may be expressed as:

$$z_i = \text{Sag of } r_1 \text{ at } p_i - \text{Sag of the lens surface at } p_i \qquad (19)$$

Let v_i denote the set of values of sagittal height of the back optic zone radius r_1 at diameter d_i. Then it is clear that:

$$z_1 = v_1 - y_1 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (20)$$

$$z_2 = v_2 - y_2 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (21)$$

$$z_3 = v_3 - y_3 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (22)$$

$$z_4 = v_4 - y_4 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (23)$$

$$z_5 = v_5 - y_5 \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (24)$$

After w_i and z_i have been calculated, the coefficients of the polynomial may be calculated by solving the following linear algebraic equations:

$$c_1 w_1^2 + c_2 w_1^3 + c_3 w_1^4 + c_4 w_1^5 + c_5 w_1^6 = z_1 \quad \dots \quad (25)$$

$$c_1 w_2^2 + c_2 w_2^3 + c_3 w_2^4 + c_4 w_2^5 + c_5 w_2^6 = z_2 \quad \dots \quad (26)$$

$$c_1 w_3^2 + c_2 w_3^3 + c_3 w_3^4 + c_4 w_3^5 + c_5 w_3^6 = z_3 \quad \dots \quad (27)$$

$$c_1 w_4^2 + c_2 w_4^3 + c_3 w_4^4 + c_4 w_4^5 + c_5 w_4^6 = z_4 \quad \dots \quad (28)$$

$$c_1 w_5^2 + c_2 w_5^3 + c_3 w_5^4 + c_4 w_5^5 + c_5 w_5^6 = z_5 \quad \dots \quad (29)$$

In vector notation, this set of equations can be expressed as

$$AC = Z \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (30)$$

where A is the matrix

$$A = \begin{matrix} w_1^2 & w_1^3 & w_1^4 & w_1^5 & w_1^6 \\ w_2^2 & w_2^3 & w_2^4 & w_2^5 & w_2^6 \\ w_3^2 & w_3^3 & w_3^4 & w_3^5 & w_3^6 \\ w_4^2 & w_4^3 & w_4^4 & w_4^5 & w_4^6 \\ w_5^2 & w_5^3 & w_5^4 & w_5^5 & w_5^6 \end{matrix} \quad \dots\dots\dots\dots \quad (31)$$

C is a vector:

$$C = \begin{matrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{matrix} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (32)$$

and Z is also a vector:

$$Z = \begin{matrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{matrix} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (33)$$

Solving matrix equation (30) gives the coefficient matrix C as:

$$C = A^{-1}Z \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (34)$$

This equation can be solved by calculating the determinant of the matrix A (*Vandermonde's determinant*).

At any given position on the curve, it is possible to see how closely the polynomial fits the lens curve by calculating the error E defined as the difference between the sagittal height of the original lens surface and the polynomial surface.

Let d_x be an arbitrary diameter less than or equal to the lens total diameter.

Then the mapping error will be the difference between the sagittal height of the original lens surface at diameter d_x and

the sagittal height of the polynomial surface at the same diameter.

Let $p_p.y$ be the distance from the point p on the polynomial to the x-axis.

The distance w_p from the point p_p to the line AB in Figure 1 is:

$$w_p = (d_x - d_1)/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (35)$$

Therefore, the sagittal distance from the point p_p to the back optic zone radius is given by:

$$z_p = 0 \text{ if } d_x < d_1 \quad \ldots\ldots\ldots\ldots\ldots (36)$$

otherwise

$$z_p = c_1 w_p^2 + c_2 w_p^3 + c_3 w_p^4 + c_4 w_p^5 + c_5 w_p^6 \quad \ldots (37)$$

Then the distance $p_p.y$ may be calculated from:

$$p_p.y = r_1 - \sqrt{r_1^2 - (d_x/2)^2} - z_p \quad \ldots\ldots\ldots (38)$$

Then let $p_c.y$ denote the sagittal height of the original lens surface 3 at the specified diameter, d_x.

The mapping error is given by the difference between $p_p.y$ and $p_c.y$:

$$E = \left| p_p.y - p_c.y \right| \quad \ldots\ldots\ldots\ldots\ldots\ldots (39)$$

The mathematical procedures described above are then utilised to create machine control software which can be used to control the action of a computer numerically controlled lathe. Once programmed, such a lathe is effectively able to convert the shape of the back surface of any analogous lens into polynomial form from a set of data constituting parameters which can be physically measured on an analogous lens such as the radii and diameters of the component curves. The lathe is then able to cut the back surface 3 of the lens 1 in a single pass to produce a smooth, aspherically curved back surface.

The machine control software will not be described as it is entirely conventional and within the capability of the skilled man.

It should also be appreciated that the above embodiment has been described by way of example only and that modifications of detail may be made within the scope of the invention.

CLAIMS

1.   A process for the manufacture of a rigid contact
lens having a smooth, aspherically curved back surface of
defined geometry which comprises selecting an analogous
lens which has the desired optical and dynamic properties
and a back surface of generally spherical geometry
comprising a co-axial multicurve having a discontinuity
at each point where the radii of adjacent component
curves of the multicurve intersect, subjecting the back
surface of the analogous lens to mathematical analysis,
using the results of the analysis to construct a
mathematical formula which defines the geometry of the
desired aspherically curved surface and using the
mathematical formula to generate data to control the
action of a shaping device which forms the aspherically
curved back surface of the lens according to the defined
geometry.

2.   A process for shaping the back surface of a rigid
contact lens to produce a smooth, aspherically curved
surface of defined geometry which comprises selecting an
analogous lens which has the desired optical and dynamic
properties and a back surface of generally spherical
geometry comprising a co-axial multicurve having a
discontinuity at each point where the radii of adjacent
component curves of the multicurve intersect, subjecting
the back surface of the analogous lens to mathematical
analysis, using the results of the analysis to construct
a mathematical formula which defines the geometry of the
desired aspherically curved surface and using the
mathematical formula to generate data to control the
action of a shaping device which forms the aspherically
curved back surface of the lens according to the defined
geometry.

3. A process according to claim 1 or claim 2 in which the back surface is rotationally symmetrical.

4. A process according to any one of the preceding claims in which the mathematical analysis involves measuring selected parameters of the analogous lens.

5. A process according to claim 4 in which the selected parameters are the radii and diameters of the component curves of the co-axial multicurve back surface.

6. A process according to claim 4 or claim 5 in which at least one additional point is selected on at least one of the component curves and the selected parameters are also measured for each such point.

7. A process according to any one of the preceding claims in which the mathematical formula is a derived polynomial.

8. A process according to claim 7 in which the order of the polynomial is determined by the number of discontinuities in the co-axial multicurve or, if at least one additional point has been selected, by the number of discontinuities and additional points.

9. A process according to any one of the preceding claims in which the mathematical formula is constructed so that its resulting surface of revolution is mathematically smooth and continuous at each point which corresponds to a discontinuity in the back surface of the analogous lens.

10. A process according to any one of the preceding claims in which the analogous lens is a 5-curve multicurve lens.

11.   A process according to claim 10 in which an additional point on the 5-curve multicurve back surface is selected.

12.   A process according to claim 11 in which the mathematical formula is a polynomial of order 6.

13.   A process according to any one of the preceding claims in which the data generated comprises a set of instructions capable of being interpreted by a control system of the shaping device.

14.   A process according to any one of the preceding claims in which the shaping device is a cutting tool.

15.   A process according to claim 14 in which the cutting tool is a computer numerically controlled lathe.

16.   A rigid contact lens having a smooth aspherically curved back surface comprising a central optic zone having a spherically curved back surface and a plurality of peripheral zones in which the radii of adjacent zones have a common tangent.

17.   A rigid contact lens according to claim 16 which comprises a central optic zone and four peripheral zones.

18.   A rigid contact lens having a smooth, aspherically curved back surface produced by a process according to any one of claims 1 to 15.

19.   A process substantially as hereinbefore described and with reference to the accompanying drawing(s).

20.   A rigid contact lens having a smooth, aspherically curved back surface substantially as hereinbefore

described and with reference to the accompanying
drawing(s).

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Category	Identity of document and relevant passage	Relevant to claims
A	GB1561892 A (WESLEY JESSEN) See p2 lines 29-47 and p3 lines 23-50	common matter
A	EP0742462 A2 (JOHNSON & JOHNSON)	.
A	US5428412 A (STOYAN) See col.5 lines 59-60	common matter
A	US5172143 A (ESSILOR)	.

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